Progress in hydro-meteorological studies in Changwu, the Loess Plateau of China

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1. Introduction

The Loess Plateau of China is characterized as semi-arid region and occupies more than one thirds of the whole Yellow River Basin. Thus accurate determination of regional evapotranspiration and hydro-meteorological studies in the area are crucial for water resources assessment of the Yellow River Basin. Because the plateau consists of not only flat tablelands but also deep river valleys, aerodynamic-based estimation of evapotranspiration is quite difficult. Another choice is the use of Atmospheric Boundary Layer (ABL) data. ABL plays an important role on the heat and water vapor exchanges between the land surface and the atmosphere. However not much is known on the diurnal and seasonal change in ABL over such complex terrain.

This study reports diurnal and seasonal changes in ABL and relationships among surface heat fluxes, ABL heights and diurnal variations in convective activities over Changwu area. For comparison, another ABL data set obtained at quite different climatic conditions in China was used.

2. Site and Observations

Our main target areas is Changwu, Shaanxi, which is located in southern part of the Loess Plateau of China (35.24° N and 107.68° E) Another is Shouxian, Anhui, characterized as flat but heterogeneous agricultural fields with relatively humid environment. The Shouxian site locates on 22.7 m A.S.L. at 32.55 N and 116.78 E.

Very similar designs (instrumentations) for measurements of surface heat fluxes and surface radiation balance were appeared at both stations. A 32-m height tower was used for those measurements at both sites. The instrumentations include three dimensional ultra-sonic anemometer (Solent R3; Gill Instruments, Ltd., UK) and open-path infrared gas analyzer (LI-7500; LI-COR, Inc., USA). Combined use of a three dimensional ultra-sonic anemometer and an open-path infrared gas analyzer reproduced surface fluxes of sensible heat and latent heat. The same type of WPR (L-28, Sumitomo Electric Industries, Ltd, Japan) was also equipped at the stations. The WPR produced vertical profiles of three dimensional wind velocity and those of echo intensity. From the echo intensity profiles, diurnal changes in ABL heights were determined using "median filtering method" (e.g. Angevine et al., 1994, 2001; White et al., 2002). Details of the instrumentation at the Shouxian site were shown in Hiyama et al. (2004) and Tanaka et al. (2007), and those at the Changwu site were shown in Hiyama et al. (2005) and Nishikawa et al. (2005).

At both stations, intensive observations were performed to obtain continuous data set of surface conditions, surface heat fluxes, ABL structure, and cloud types and those amounts. In 2005, the intensive observation period (IOP) at Shouxian site was mostly the same as that at Changwu station; from middle of May to middle of July (nearly two months). We used the data of cloud type and amount, for comparison of diurnal and seasonal variations of convective activities with the relation of ABL properties.

3. Results

In the Shouxian area, obvious seasonal changes in vegetation (i.e., agricultural activity) affected the ABL development. Tanaka et al. (2006) showed that daily maxima of ABL height corresponded well to the daytime averaged buoyancy flux, but the relationship was less clear after irrigation. On the whole, seasonal change in ABL height was similar to that of surface sensible heat flux. Surface dryness and thus surface sensible heat flux are high but water vapor content in the lower atmosphere is low before the Meiyu onset. In this case, deeper ABL can be produced by high buoyancy flux but it rarely generates deep convective clouds, except when synoptic weather affects the region. After the Meiyu onset, because land surface became rice paddy with shallow water bodies, the latent heat flux dominated compared to the sensible heat flux. This made daily maxima of ABL shallower than those in the pre-Meiyu. Thus in spite of high relative humidity, deep convection has rarely been observed unless synoptic weather affected the region similarly.

On the contrary, seasonal change in surface heat fluxes and daily maxima of ABL height at Changwu were relatively unclear (Fig. 1). From the climatological point of view, horizontal water vapor flux became larger after middle of June. The water vapor comes into the region mainly from southwestern direction. In the mid-summer season, precipitation occurs with around 5 - 10 days intervals. After a precipitation event to subsequent precipitation event, surface sensible heat flux gradually increases due to surface wetness decreasing. This affects day to day changes in ABL developments (i.e. producing deeper daily maxima in ABL height). Before a subsequent precipitation event, the region is synoptically covered by a heat-low system. This caused strong updraft motions (e.g. thermal) within the ABL, which sometime penetrate the ABL top in the afternoon. This phenomenon might be closely related to active cumulus convection (Fig. 2). In this case, ABL was typically shallow before noon and it suddenly developed around noon. Clear wind direction change was also observed in this situation; the direction was northerly in the morning, easterly around noon, and southerly in the afternoon. This diurnal wind change seemed to be corresponded to local circulation (but this is not confirmed yet). In the afternoon, updraft motions (e.g. thermal) were so strong that vertical winds easily penetrated ABL top. This ABL development process seemed to be unique and basically different from that observed under high pressure-covered fine weather conditions, such like at Shouxian.

In case that horizontal water vapor flux and water vapor content became larger especially in the lower atmosphere, deep convective cloud often appeared in the Changwu region. Precipitation amount due to such convective activity accounted for around 25 % to the annual precipitation in the region.

4. Summary and Recommendation

Based on mid-summer temporal variations in ABL structures observed at relatively humid (Shouxian) and at semi-arid (Changwu) environments, seasonal and diurnal changes in the ABL height and vertical wind features were compared in terms of synoptic condition and surface heat fluxes. Seasonal change in surface condition at Changwu was relatively unclear. Synoptically, horizontal water vapor flux became larger after middle of June. Thus seasonal maxima of precipitation began to appear after the middle of June. The precipitation occurred with around 5 - 10 days intervals in this season. Before the precipitation event, i.e. after a long no-rainfall period, surface sensible heat flux became higher due to low surface soil moisture. In this case a heat-low system usually covered the region, and the deeper ABL in the afternoon was frequently observed. In such case, strong updraft motions (e.g. thermal) were frequently observed and sometime penetrated the ABL top with the combination of heat low situation (weak capping inversion).

Because there are various climate zones in China, this kind of research on "ABL climatology" would be encouraged more in future.

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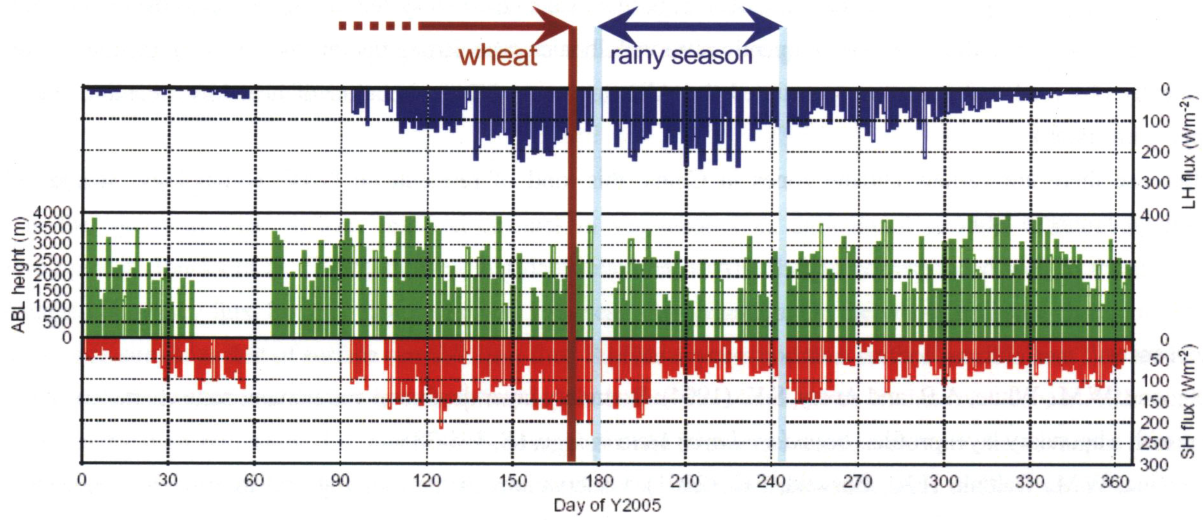

Figure 1 Seasonal changes in daily maximum ABL heights (green bars), sensible heat fluxes (red bars), and latent heat fluxes (blue bars) observed at Changwu station. The ABL heights were estimated from WPR echo intensity using median filtering method. The sensible and latent heat fluxes were measured at 10-m height. Also indicated in the figure were dominant land cover and rainy season in the region.

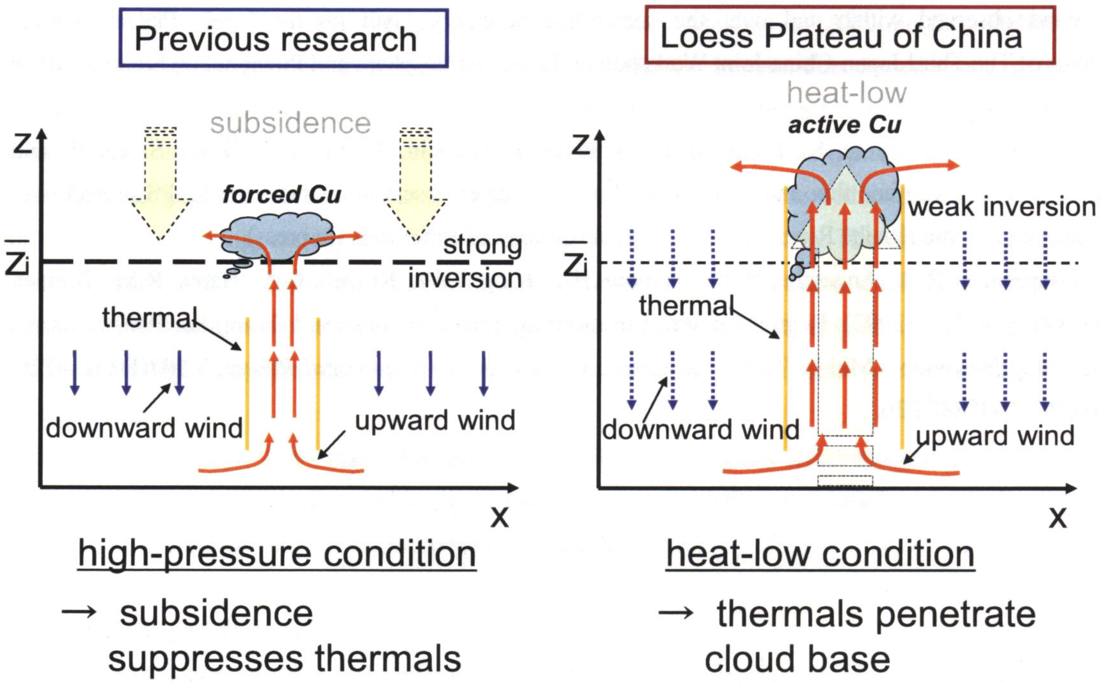

Figure 2 Schematic diagrams indicating vertical wind motions within and above ABL, in conjunction with cumulus convections and synoptic conditions.